APPENDIX E
DESIGN EXAMPLES

The following examples illustrate the approach and the procedures used for the design of a full-scale AOP treatment systems.

EXAMPLE No.1 : UV/H_2O_2 system.

A. Background

Case A involves the treatment of groundwater in an abandoned chemical plant. The groundwater was found to contain DCA, Vinyl chloride and other organic compounds. The owner is the principal party who is responsible for the clean-up of the facility.

Followings are water characterization (Section 7) results:

Influent characteristics:

TCE	100 - 400 ppb
DCE	70 - 200 ppb
Vinyl chloride	50 - 80 ppb
pH	6.5
Iron	< 5 ppm
Carbonate	<200 ppm
Total solids	50 ppm
Maximum flow	100 gpm (0.144 MGD) as results of pump tests

Effluent clean-up criteria:

VOCs	< 5 ppb
pH	7-9
TSS	<30 ppm

B. Treatment approach:

Several treatment options were evaluated which include:

- Stripping followed by activated carbon
- UV/Ozone/Peroxide
- UV/Peroxide

Because the facility is located proximity to a large residential area, the owner preferred using a low-visibility, quiet treatment method that could consistently destroy the contaminants to meet the clean-up criteria 5 ppb of VOC*s.

Based on these requirements, AOP treatment is preferred to stripping and carbon. Based on chemical characteristic of contaminants, both UV/H_2O_2 and UV/O_3/H_2O_2 technologies can be used. A preliminary economic analysis was carried out to determine which AOP technology is used. The owner selected the UV/H_2O_2 based on a short clean-up time, a low capital cost and a low profile approach (no ozone warning sign in front of the treatment facility)

Treatability study of groundwater using UV/H_2O_2 testing unit resulted in the following recommendations:

! Pretreatment to remove suspended solids to less than 20 ppm with pressure bag filter at 5-micron size.

! No pH adjust before oxidation

! Water flow 5 gpm

! H_2O_2 dosage 40 mg/l

! HRT 20 minutes

! UV dose 4 KW/l000 gals

! pH readjust to between 7.5 - 9 before discharge.

! Hydrogen peroxide 50 percent by weight is used.

! Equalization time 2 hours

C. Develop a projected Full-Scale Design & capital expense and anticipated annual operating cost

Design parameters:

Flow maximum:	100	gpm
TCE	400	ppb
DCE	200	ppb
Vinyl chloride	80	ppb
Hydrogen peroxide	40	ppm

Pretreatment:

Equalization tank (EO)

EQ volume V(gal) = flow (gpm) x equalization time (minute):
V = 100 gal/min x 2 hr x 60 mm/hr = 12,000 gallons.

Solids removal. Bag filter will be used for solids removal. Commercial type pressure filters are available based on hydraulic and solids loading to the filter. In this case two pressure cartridge filter model is recommended. Cartridge filters should be installed in parallel to assure the continuity of operation.

Transfer pumps. Two transfer pumps, one as a standby, of 120 gpm each are used. There is no unusual requirements for the transfer pumps. Pump requirements should comply with the CEGS 11211 Pumps Specifications.

Oxidation unit. The size and the configuration of the reaction tank are usually designed by the vendor who supplies the AOP unit. However, the volume of the reactor tank is provided to give the designer an understanding of the issue.

Based on 20 minutes Hydraulic Retention Time (HRT), the volume V of the UV reactor is:

V = Max. flow rate (gpm) x HRT (minutes)

V = 100 gal/mm x 20 minutes = 2000 gallons.

UV Dose

UV dose based on studies: 4 kWh/1000 gallons

UV requirement is: 4 kWh/1000gals x 100gpm x 60min/hr/1000gals
= 24 kW

Therefore, one standard unit of 24 kW or 2 x 12 kW units are used.

Oxidant requirements

$$H_2O_2 \text{ requirements} = \frac{40 \text{ mg}}{\text{L}} \times \frac{1.44 \times 10^5 \text{gal}}{\text{Day}} \times \frac{3.785\text{L}}{\text{gal}} \times \frac{\text{lb}}{4.54\times10^5\text{mg}}$$

= 48 lbs/day @ 100%

H_2O_2 storage tank:

- The H_2O_2 storage tank volume is sized for at least one month of supply. The volume of storage tank is calculated as follow:

- H_2O_2 required to store = 48 lbs/day x 30 day = 1440 lbs or 2440 lbs at 50 percent concentration.

- At 50% percent, H_2O_2 weighs 10 lbs per gallon:
  V = 2440/10 = 240 gallons. Use a 300-gallon carboy as standard size.

H_2O_2 feed pumps: Metering pumps capacity is designed based on H_2O_2 feed rate of 50% concentration. Two metering pumps, one as a spare, are designed. The metering pump capacity is designed as follow:

At 50% percent, H_2O_2 requirement is 2 x 48lbs/day or 4lbs/hr.

Feed pump capacity = (4.0 lbs/hr)/10 lbs = 0.4 gal/hr, use 1 GPH metering pump.

Assuming that the reaction tank operates at 10 psi, and the line losses are 10 psi (including control valves), the metering pump should have a total dynamic head (TDH) of:

TDH =10 + 10 = 20 Psi.

Metering pump specification: 1 GPH @ 20 psi

pH adjustment. Since the effluent pH = 6.5, a base such as sodium hydroxide will be used to bring the pH to a range 7.5 to 9 before discharge. pH adjustment is not calculated in this example since it is a complicated calculation, use pH controller option for pH adjustment.

Effluent holding tank. Dependent on project specific, an effluent holding tank may be used to store the effluent for quality check to protect from continuous discharge of non-compliance effluent to the environment.

The capacity of the effluent tank, if required, is sized based on the water flow and the retention time. Assuming a 4-hour retention time is required:

$$\text{Volume } V(\text{gal}) = \text{flow (gpm)} \times \text{retention time (minute)}$$

$$V = \frac{100 \text{ gal}}{\text{mm}} \times 4\text{hr} \times \frac{60\text{min}}{\text{hr}} = 2{,}400 \text{ gallons.}$$

EXAMPLE No.2 : UV/O_3/H_2O_2, system

A. Background

Site B is an old pesticides manufacturer plant. The groundwater is contaminated with various organic compounds as shown on the groundwater analysis data below.

Groundwater Analysis. The site is to be remediate by a pump and treat system. From previous studies, The Remediation Action called for and d with both free cyanide and complexed cyanide along with other organic compounds.

Influent characteristics:

Cyanide	20 - 35 ppm
Complexed cyanide	50 - 80 ppm
TOC	100 - 200 ppm
pH	6.5
Iron	<5 ppm
Carbonate	<200 ppm

Total solids <30 ppm
Flow 25 gpm or 36,000 gals/day

Effluent limitation:

VOC < 5 ppb

Based on the results of a treatability study and a pilot scale testing, the UV/Ozone technology is selected for the site remediation. Followings are recommended design parameters:

Solids removal not required

Ozone dose 100 mg/L for free cyanide @ HRT = 2 minutes

Ozone dose 30 mg/L for complexed cyanide @ HRT = 40 minutes

No catalyst is required

Ozone in off-gas > 0.2 gram/m^3 NTP.

B. Design calculations

Based on the treatability study and pilot testing recommendations, the following calculations are performed:

1. pH adjustment: Since high pH favors the reaction of UV/ozone formation for hydroxyl radicals production, pH adjust to 9 before oxidation is recommended. pH adjustment is discussed in the example No.1 above.

2. Oxidation unit. Based on the information provided, there are two different reaction rates in the oxidation unit: the mass transfer with high ozone consumption in a short time, and the rate transfer with limit rate transfer in a long hydraulic retention time. The reaction tank is therefore should be designed for two cases. The oxidation unit which includes reaction tank(s) and contacting unit(s) is usually designed by the vendor who supplies the AOP equipment; therefore, the detailed design is not performed.

Mass transfer case: Reactor tank volume: V = 25 gpm x 2 mm = 50 gallons. Since the reactor should house the ozone contacting device, a larger reactor volume will be required.

$$\text{Ozone requirement:} = \frac{100\ \text{mg}}{\text{L}} \times \frac{1500\ \text{gals}}{\text{hr}} \times \frac{3.785\text{L}}{\text{gal}} \times \frac{\text{lb}}{4.54\text{x}10^5\text{mg}}$$
$$= 1.25\ \text{lbs/hr}$$

Rate transfer case. Reaction tank volume : V = 25 gpm x 40 min = 1000 gallons. Since the reactor should house the ozone contacting device, a larger reactor volume will be required.

$$\text{Ozone requirement:} = \frac{30\ \text{mg}}{\text{L}} \times \frac{1500\ \text{gals}}{\text{hr}} \times \frac{3.785\text{L}}{\text{gal}} \times \frac{\text{lb}}{4.54\text{x}10^5\text{mg}}$$
$$= 0.375\ \text{lbs/hr}$$

Hence, the total ozone requirement is 1.625 lb/hr. Using a safety factor of 1.5, a 2.5 lbs/hr ozonator is selected.

Ozone contacting unit: Since the solids are low, the fine bubble contacting device can be used.

Ozone destruction unit: The fact that ozone gas is bubbled through the contaminated water, ozone and VOC are expected to be stripped out and since the off-gas contains more than 0.2 g/m^3 of ozone, a ozone destruction unit should be required. This unit can be a catalytic ozone decomposer or a thermal ozone destruction as well.

3. Effluent holding tank

The effluent holding tank is recommended to protect from continuous discharge of non-compliance effluent to the environment. The capacity of the effluent tank is designed based on the retention time in the tank. A 4 hours retention time is suggested.

Volume V (gal) = flow (gpm) X retention time (minute)

$$V = 25\ \frac{gal}{min} \times 4hr \times 60\ \frac{min}{hr} = 6000 \text{ gallons.}$$

4. Off-gas recycle

Since the off gas contains excess ozone, recycle of the off gas to the first stage reactor should be considered.

EXAMPLE No.3

A. Background

The groundwater on site C is contaminated with volatile Organic compounds, chlorinated compounds, and pesticides.

Highest level of some of the contaminants in the groundwater:

Benzene	26.0 ppb
Chloroethane	24.0 ppb
Chloroform	29.0 ppb
PCE	140.0 ppb
TCE	2108.0 ppb
Vinyl Chloride	1100.0 ppb
pH	7.2

Based on the results of a treatability study, a UV/O_3/H_2O_2 system is selected for the site remediation. At the influent pH and an HRT of 40 minutes, the optimum peroxide to ozone dosage was found to be 0.33. The optimum design parameters are:

H_2O_2 dosage	25 mg/l
O_3 dosage	75 mg/1
HRT	40 minutes
pH	7.2

No catalyst is required

B. Design Calculations:

The following design and calculations are performed:

1. Design flow rate:

Maximum: 15 gpm

2. Equalization tank CEO)

To insure a consistent performance of the AOP treatment system, an EQ tank is required to smooth out the flow and concentrations.

EQ volume V(gal) = flow (gpm) x retention time (minute), a value of 4 hours is recommended.

$$V = 15\ \frac{gal}{min} \times 4hr \times \frac{60min}{hr} = 3{,}600 \text{ gallons.}$$

3. Transfer pumps

Two transfer pumps, one as a standby, are required to transfer water from the EQ tank to the oxidation unit. The pumps should have a design flow of 15 gpm each with enough TDH to overcome the line losses through the cartridge filter and the piping from the EQ tank to the oxidation unit.

4. Oxidation unit

The size and the configuration of the reaction vessels are usually designed by the vendor who supplies the AOP unit. Therefore, the reaction tank detailed design will not be given in this ETL. However, the volume of the reactor tank is provided:

V = Max. Flow Rate x HRT

$$V = 15\ \frac{gal}{min} \times 40 \text{ minutes} = 600 \text{ gallons.}$$

A larger volume will be required to allow for the ozone gas disengagement and the gas contacting device.

5. Hydrogen Peroxide requirements

H_2O_2 requirements = 4.5 lbs/day @ 100%

H_2O_2 storage tank: A 50% H2O2 concentration is used to feed the reactor. The volume of storage tank is calculated as follow:

H_2O_2 required to store = 4.5 lbs/day x 30 day
= 135 lbs @ 100% or 270 lbs at 50% per month.

At 50% concentration, HO_2 weighs 10 lbs per gallon, therefore:

V = 270/10 = 27 gals. Use 55 gallon drum as standard size.

H_2O_2 feed Pumps: Two metering pumps, one as a spare, are required. The metering pump capacity is designed as follow:

At 50% percent, H_2O_2 requirement is 9.0 lbs/day or 0.375 lbs/hr.

The metering pump capacity is:

(0.375 lbs/hr)/(10 lbs/gallon) = 0.0375 GPH, use 0.50 GPH pump.

Assuming that the reaction tank operates at 10 psi, and the line losses are 10 psi (including control valves), the design metering pump head TDH = 10 + 10 = 20 psi.

Metering pump specification: 0.50 GPH @ 20 psi

6. Ozone Requirements

Ozone Requirement: = (gpm x 8.34 x ppm 03 dose) /694
= (15 x 8.34 x 75)/694 = 13.5 lb/day or
= 0.56 lb/hr

Allowing a safety factor of 1.5, a 1.0 lb/hr ozone generator is selected.

Ozone Contacting Unit: Since, no solid concentration is reported, fine bubble diffusers can be used.

Ozone Destruction Unit: The off-gas from the reaction vessel is expected to have ozone and VOCs, especially vinyl chloride. Hence, an ozone destruction unit is required.

7. Effluent holding tank

The effluent holding tank is recommended to protect from continuous discharge of non-compliance effluent to the environment. The capacity of the effluent tank is designed based on the retention time in the tank. A 4 hours retention time is suggested.

$$\text{Volume V (gal)} = \text{flow (gpm)} \times \text{retention time (minute)}$$

$$V = 15\,\frac{\text{gal}}{\text{min}} \times 4\text{hr} \times 60\,\frac{\text{min}}{\text{hr}} = 3{,}500 \text{ gallons.}$$

8. Off-gas recycle

Since the off gas may contain ozone and VOCs, recycle of the off-gas to the reactor should be considered.